FORESTRY MITIGATION POTENTIAL AND COSTS IN DEVELOPING COUNTRIES – PREFACE

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Forestry options to mitigate climate change are an important element of approaches to reduce greenhouse gas emissions. The Intergovernmental Panel on Climate Change released a special report on Land use, land-use change and forestry in 2000. One element of this report focused on the technical potential of forestry options to address climatic change. This potential was estimated to be of the order of 1 Pg C yr^{-1} in 2010 or enough to offset a large portion of the annual GHG emissions from this sector during the 1990s. Results from the set of studies in this volume complement that estimate. The studies focused on Brazil, China, India, Indonesia, Mexico, the Philippines and Tanzania. Researchers from this group of countries have worked together as members of the Tropical Forestry and Global Change Research Network (F-7) for the past ten years. The main goal of their work has been to estimate the (1) GHG emissions from these and neighboring countries, (2) potential for emissions avoidance and carbon sequestration, and (3) monetary and other costs and benefits of forestry mitigation options, and (4) to assess project opportunities, including the issues of baselines, additionality, leakage, and monitoring and verification. Researchers have published three earlier volumes on these topics (Sathaye and Makundi 1995; Fearnside 1997; Sathaye et al. 1997). This set of studies constitutes the fourth volume. The F7 Network is organized and coordinated by the Lawrence Berkeley National Laboratory, University of California, Berkeley, CA, and is supported by the US Environmental Protection Agency.

This set of studies focused on estimating the costs of, and the potential for, carbon sequestration and emissions avoidance. Each study was conducted by one or more authors in the country, and except for Brazil and China, the studies evaluated mitigation options that apply to the forest sector of the entire country. The Brazil study reported results for the Amazon region and the China one focused on the three main forested regions of the country. Due to projected deforestation, several countries, Mexico, the Philippines, Indonesia, and Tanzania, project a decline in vegetation biomass and carbon. The mitigation options analyzed here slow this decline but are not sufficient to reverse it in all countries. Cost estimates for emissions avoidance are uniformly high due to the high opportunity cost of land.

The studies show a significant mitigation potential about 6 Pg C by 2030, bulk of which may be achieved at costs that range below $20 per Mg C. About half the potential is estimated as being achievable at a negative cost or net economic benefit, when evaluated at discount rates between 10% and 12%. Negative cost arises because the revenues from the sale of non-carbon products exceed the costs of these options. Many barriers, particularly the limited availability of financing

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for this sector, however, limit the ability of project developers from achieving these goals. Other barriers, such as improper legal tenure to land and social organization for mobilizing carbon resources, will also limit the potential by an unknown amount in each country. The F7 group is conducting further studies on the role of barriers, and the extent to which these prevent the adoption of what appear to be cost-effective options.

The above range of cost estimates for the forestry options is comparable to that reported by the IPCC using bottom-up studies for the energy sector (Banuri et al. 2001). Costs reported vary from negative values to about \$ 100 per Mg C for a variety of options, and emissions in 2010 and 2020 could be brought below 2000 levels provided barriers to the deployment of mitigation options are overcome.

At the project level, baselines, additionality, permanence, leakage, and monitoring and verification have been noted as key issues that would affect estimates of costs and carbon potential (Brown et al. 2000). A noteworthy feature of the forestry mitigation studies reported in this volume is that they estimate carbon potential with respect to baseline biomass and carbon content, and for scenario analysis they compare one or more mitigation scenarios with a baseline scenario. The reported costs and potential are thus incremental to a baseline scenario of biomass growth and land-use change. And since a large portion of the carbon is available at negative or low cost, and is not being tapped, it may be deemed additional. Costs include those for monitoring of carbon content. The studies make no assumptions about permanence, but within their time horizon they assume that the carbon is not lost through disturbances. Insuring against loss of carbon will increase the estimated costs, and the loss of carbon will decrease the estimated carbon potential. Leakage is addressed indirectly, since the studies account for opportunity costs of all mitigation options, including the forest protection option. The expectation being that compensation paid to deforesters would dissuade them from deforestation activities elsewhere.

This set of studies thus forms the basis for estimating the mitigation potential and costs of project-based activities. The studies will also be of use to modelers interested in estimating the global costs and mitigation potential of options across sectors.

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POTENTIAL AND COST OF CARBON SEQUESTRATION IN THE TANZANIAN FOREST SECTOR *

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Abstract. The forest sector in Tanzania offers ample opportunities to reduce greenhouse gas emissions (GHG) and sequester carbon (C) in terrestrial ecosystems. More than 90% of the country's demand for primary energy is obtained from biomass mostly procured unsustainably from natural forests. This study examines the potential to sequester C through expansion of forest plantations aimed at reducing the dependence on natural forest for wood fuel production, as well as increase the country's output of industrial wood from plantations. These were compared ton conservation options in the tropical and miombo ecosystems. Three sequestration options were analyzed, involving the establishment of short rotation and long rotation plantations on about 1.7×10^6 hectares. The short rotation community forestry option has a potential to sequester an equilibrium amount of 197.4×10^6 Mg C by 2024 at a net benefit of \$ 79.5×10^6, while yielding a NPV of \$ 0.46 Mg^{-1} C. The long rotation options for softwood and hardwood plantations will reach an equilibrium sequestration of 5.6 and 11.8×10^6 Mg C at a negative NPV of \$ 0.60 Mg^{-1} C and \$ 0.32 Mg^{-1} C. The three options provide cost competitive opportunities for sequestering about 7.5×10^6 Mg C yr^{-1} while providing desired forest products and easing the pressure on the natural forests in Tanzania. The endowment costs of the sequestration options were all found to be cheaper than the emission avoidance cost for conservation options which had an average cost of \$ 1.27 Mg^{-1} C, rising to \$ 7.5 Mg^{-1} C under some assumptions on vulnerability to encroachment. The estimates shown here may represent the upper bound, because the actual potential will be influenced by market prices for inputs and forest products, land use policy constraints and the structure of global C transactions.

Keywords: C sequestration, cost of GHG mitigation, mitigation potential, Tanzania

1. Introduction

In June 1992, Tanzania along with over 160 other countries signed the United Nations Framework Convention on Climate Change (UNFCCC) at the Earth Summit in Rio de Janeiro, Brazil, which came into force in March 1994. Tanzania ratified the UNFCCC in March 1996. Arising from the UNFCCC, the Third Conference of the Parties (COP3) developed the Kyoto Protocol in 1997, which would guide the countries in meeting their obligations under the Rio Treaty to limit the amount of GHG emitted into the atmosphere from reaching levels which could destabilize the global climate (UNFCCC 1997).

The Kyoto Protocol established binding GHG emissions reduction targets from their 1990 emission levels for industrialized countries and countries in transition

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(the 'Annex B countries), by the first commitment period (2008–2012). In order to meet their GHG emissions reduction obligations under the Protocol, the Annex B countries can use three international flexibility mechanisms provided for in the Protocol, i.e., Joint Implementation (JI – Article 6), Clean Development Mechanism (CDM – Article 12) and Emissions Trading (ET – Article 17). Among these mechanisms, the most relevant for the participation of developing countries is Article 12.

CDM allows Annex B countries to implement projects in countries with no binding emissions reduction targets (developing countries), and some or all of the additional GHG emissions savings from the project may be credited to the Annex B country, depending on agreements among the parties and the implementation modalities. The Kyoto Protocol has a provision for pre-commitment period mitigation activities, whereby credits accrued from projects started between 2000 and 2008 can be claimed as certified emissions reductions (CERs), sometimes referred to as early crediting. Following decisions at the UNFCCC COP6bis, the land use sector was included in the areas that can be used to mitigate GHG emissions, a decision which increases the opportunities for land abundant countries like Tanzania to play a significant role in the global efforts to stabilize atmospheric GHGs (UNFCCC 2001).

Africa's net emissions of GHGs in the last decade were estimated at 300×10^6 Mg C yr^{-1}, constituting about 4 percent of the global emissions (Okoth-Ogendo and Ojwang 1995). Africa's share is not projected to increase significantly in the next decade. However, there are significant opportunities for C sequestration in the land use, land-use change and forestry sector especially through afforestation, reforestation and conservation activities.

The objective of this study is to assess the potential for GHG emissions reduction and C sequestration in the forest sector of Tanzania. The study analyzes the potential for C sequestration and the associated costs and benefits for three afforestation activities – short rotation community forestry, long rotation softwood plantations and long rotation hardwood plantations. The three sequestration activities are also compared to ecosystem conservation options. The estimated potential examined here shows an upper bound for C sequestration in mitigation projects in the three candidate activities. The actual potential and costs of implementation will be influenced by barriers and market conditions for inputs and forest products, including the market for C.

1.1. Past studies on GHG inventory and mitigation in Tanzania

According to Articles 4 and 12 of the UNFCCC, parties are required to submit their Initial National Communication (INC), which should include a national inventory of sources of GHGs and their removal by sinks, identification of vulnerable sectors and actions to be taken for sustainable future socio-economic development. With the support of the Global Environment Facility (GEF), the United

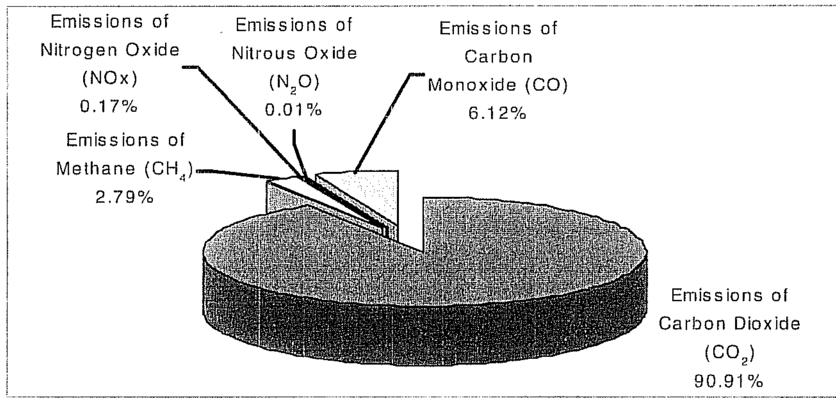

Figure 1. GHG emissions in Tanzania for 1990 base-year. Source: CEEST (2001).

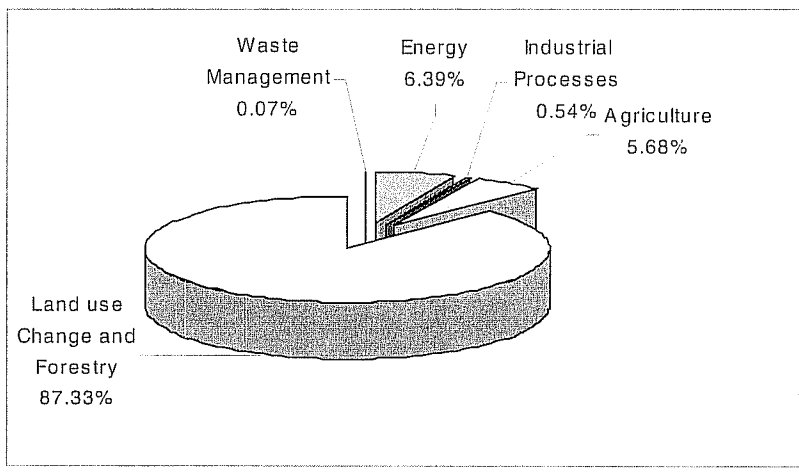

Figure 2. 1990 GHG emissions by economic sector in Tanzania Source: CEEST (2001).

Nations Environment Programme (UNEP) and the United States Country Studies Program (USCSP), Tanzania completed the GHG inventory for the INC in September 1999, with the final draft completed in 2001 (CEEST 2001). The study applied the guidelines set by the UN Intergovernmental Panel on Climate Change (IPCC) for carrying out a national GHG inventory (IPCC 1995).

The inventory was carried out for 1990 base year covering energy, industrial processes, agriculture, land-use change and forestry, and waste management sectors. As shown in Figures 1 and 2, the bulk of the emissions come from the land-use change and forestry sector (87.3%) with agriculture contributing 5.7%. Over 90% of the national emissions in 1990 were CO_2. Given the concentration of emissions in the land use sectors, any mitigation activity to reduce GHG emissions has to focus on this sector.

The initial national communication study estimated that the land use change and forestry sector emitted 56.7×10^6 Mg CO_2 while sequestering 3.7×10^6 Mg CO_2 in 1990 giving a net emission of 52.9×10^6 Mg CO_2.

Another study which was undertaken using a different methodology (Makundi and Okiting'ati 2000) gave a much larger estimate of emissions from forestry. This study which used the COPATH model which was developed for estimating carbon flows from forestry given specific forestry conversion modes (Makundi et al. 1995), gave an estimate of 168×10^6 Mg CO_2 of emissions and 64×10^6 Mg CO_2 of removals, leaving a net committed emissions from the sector at 104×10^6 Mg CO_2, or 28.4×10^6 Mg C. These two estimates can not be directly compared because of the differences in the assumptions and pools included. The results reported in the INC used the UN Intergovernmental Panel on Climate Change (IPCC) methodology which is much more aggregate in terms of ecosystems studied, and the study applied default emission coefficients from the IPCC guidelines, whereas the one showing much higher emissions used more disaggregate forest types, with local ecosystem-specific emission factors. More importantly, the latter included C stocks and flux in belowground biomass, and allocated biomass removal to different decay categories, whereas the INC study assigns all product pool to the year of removal. Furthermore, the emissions from decay and soil C loss in the IPCC methodology is estimated from 10 and 25 years respectively prior to the base year, which underestimates this emission source because the land conversion had accelerated significantly by 1990. The average estimated deforestation rate for the 1980's was about 300×10^3 ha yr^{-1}, which is estimated to have more than doubled by 1990 (Makundi and Okiting'ati 2000). These factors account for most of the difference between the two estimates.

2. Potential Mitigation Activities in the Land Use Sector

Due to the land use characteristics in Tanzania, the forest sector offers mitigation opportunities in emission reduction (conservation and protection), and in C sequestration (afforestation and reforestation), depending on policies and tenurial arrangements. About 6 percent of the land area in Tanzania is currently under cultivation, and another 40 percent is classified as rough grazing land, with most of the rest falling under forests and woodlands estimated at about 42×10^6 ha. It is further estimated that close to half of the country's land area is arable and as such amenable to supporting tree crops (ODA 1987).

Deforestation and forest degradation has been increasing with the rapid increase in population, which is mainly land-dependent. Forest land is converted to agricultural land as well as depleted for production of woodfuel, especially charcoal, as well as logging and forest fires (Hosier 1993). Unique uses of trees such as carving and traditional bee-keeping lead to significant loses of natural forests. For example, Smith (1966) estimated that about 500×10^3 trees were killed annually in Tanzania because of removal of their bark for making hives. Since most debarked trees are from open woodlands with low stocking density averaging about 50 trees ha^{-1}, this activity leads to an equivalent loss of about 10×10^3 ha yr^{-1}. Also, removal of poles and posts for household purposes has been estimated at 834×10^3 m^3 yr^{-1} which degrades natural woodlands and reduces the amount of timber harvested as final crop per hectare (Dykstra 1983). Mitigation programs that can satisfy part of these demands on the natural forests have potential for C sequestration benefits.

The conservation mitigation options are based on the forested area which consists mostly of natural miombo woodlands, sparsely populated with a variety of species, the dominant genera being *Brachestegia* and *Julbernedia*. The miombo woodlands have low stocking, averaging about 50 m^3 ha^{-1} with an annual biomass increase between 2 to 4 m^3 ha^{-1} (Malimbwi et al. 1994). About 25% of the area shown as miombo woodlands is a substantial pre-climax ecosystem of transition woodlands which serve as an important source of woodfuel in the drier parts of the country. Here there are significant opportunities to replace the source of woodfuel by short rotation plantations.

2.1. SHORT ROTATION COMMUNITY PLANTATIONS

It is estimated that more than 90% of roundwood removals from the forest estate is dedicated to firewood and charcoal (Makundi and Okiting'ati 1995 op cit.). About 70% of the deforestation in the country is related to woodfuel provision, with 43% as direct removals and 27% occurring during conversion of forest land to agriculture where the wood is used for fuel.

The primary mitigation options in bioenergy which could take advantage of the structure of demand and supply of woodfuel in Tanzania include the establishment of woodfuel plantations, increasing agroforestry practices, and improving the efficiency of charcoal production and woodfuel stoves. This study focuses on establishment of short rotation community plantations that will produce mostly fuel wood, but also poles, chiplogs and sawlogs.

This mitigation scenario involves implementation of the Tanzania Forest Action Plan (MLNRT 1989) for establishing community short rotation woodlots to meet about 50% of the projected demand for woodfuel, poles and logs for communities. This is a plan which was envisioned in the mid-1980s to supply the country with these products through community plantations scattered throughout the country, initially involving planting 12×10^3 ha yr^{-1} in 100 villages, gradually growing to 120×10^3 ha annually in a total of 3,000 villages or settlements by 2016. This rate is maintained for 8 more years in order to have equal areas planted providing wood without big annual fluctuations. Since the program was essentially not implemented for a variety of reasons, this study seeks to analyze it as a mitigation program, with its implementation beginning in the year 2000 instead of 1990 as previously planned.

The program would involve different short rotation species with rotation ages ranging between 6–12 years. For analytical purposes, we assume an average 8-year rotation for the whole program, and use the parameters for *Eucalyptus* spp., which is the most common species in the existing community woodlots (Table III). We assume a growth rate of 0.02 m^3 yr^{-1} for each tree, with a density of 1800 trees ha^{-1} for initial stocking, even though the more productive sites do produce about 0.03 m^3 yr^{-1} per tree.

The scenario proposed here involves the conversion of about 1.7×10^6 ha of woodlands to short rotation plantations terminating the conversion in 2024, assuming that the demand for these products will have peaked, and the plantations are managed in perpetual rotations. As earlier mentioned, this amount of biomass will provide about 50% of the country's woodfuel demand mostly used for cooking and heating. Though some construction wood is expected from this option, the natural woodlands will continue to be the main source of specialty products coming from natural forests.

The land for this program is assumed to be that which is proximal to the targeted communities and available for afforestation. In many cases this will be the degraded woodlands from which the communities currently obtain woodfuel. The area under consideration for the program will constitute only a small proportion of the more than 40×10^6 ha of woodlands in the country. The plantations will be managed in perpetual rotations, involving a combination of coppicing and direct planting, depending on species and local conditions.

2.2. Short Rotation Softwood Plantations

Currently, Tanzania has very small forest area under industrial plantations. The industrial forest estate is less than 100×10^3 ha scattered over 20 small projects across the country. The bulk of the country's timber demand is obtained from natural forests. In order to reduce the depletion of natural forests, there is a need to expand the forest plantations, specifically the fast growing species. Under TFAP, a proposal was put forth to increase the softwood plantations in the country as per profile of projects described under forest management.

This option is specifically intended to expand the 40×10^3 ha Sao Hill forest plantation in southern Tanzania by 1×10^3 ha yr^{-1} for 25 years, managed in perpetual rotations. The plantation currently consists mostly of pines and cypress, with less than 3×10^3 ha of hardwoods. It supplies logs to the Southern Paper Mills and Sao Hill sawmill and the expansion is intended to cover the increase in demand for softwood timber in the future. Some of the pulp and lumber could also supply the rising demand in neighboring countries.

The high productivity of the area will enable most of the expansion to take place in yield site-class II and III, with an average mean annual increment (MAI) of 30 m^3 ha^{-1} yr^{-1}, and a timber rotation of 25 years. For chiplogs, the rotation can be as low as 17 years, but for simplicity of estimation, we assume the same rotation period, and leave the partitioning between the two products to be determined by silvicultural considerations, especially through thinning schedules.

2.3. Long Rotation Hardwood Plantations

Since all timber from natural forests is hardwood, there has not been a large push towards establishing extensive hardwood plantations. Currently, Tanzania has about 10×10^3 ha of industrial hardwood plantations, with another 10×10^3 ha or so of black wattle (for tannin extract) in the southern highlands, northeast and small amounts in the lake region. There are some small patches of privately owned hardwood plantations such as rubber and *Allanblakia* (for oil), but the total area is much less than the industrial hardwood plantations. The TFAP proposed to expand the hardwood plantations by planting 1.5×10^3 ha of hardwoods annually for 18 years. In this study, we extend the expansion program to cover the whole rotation (60 years), with an expectation that the demand for fine hardwoods can not sustainably be procured from the natural forests, and as such it must be met by plantation forestry. Furthermore, any excess production from this program can be absorbed by the import market for specialty hardwoods in industrialized countries.

The plan calls for planting a variety of species, mostly *Grevillea robusta, Tectona grandis* (teak), *Acacia seyal* and *Acacia mearnsii* (black wattle). Since there are close to 3000 ha of teak plantations in the country already (e.g., Longuza and Mtibwa), we used teak as the average species for estimating the mitigation potential for hardwoods. Teak also happens to have a long rotation period (60 years for site class II) and as such it allows us to examine issues related to mitigation activities whose timber benefits are far into the future, while most of the costs are near term. The productivity of the intended areas is estimated at a MAI of 10 m^3 ha^{-1} yr^{-1} (Ahlback 1988).

2.4. Forest Protection and Conservation

Though conservation activities are not eligible under Article 12 of the Protocol, they could be implemented under various other initiatives, including the Special Climate Change Fund agreed to at COP6bis on the implementation of the Buenos Aires Plan of Action (UNFCCC 2001, op cit.) and/or other bilateral arrangements. Regardless of the platform on which emission reduction activities are undertaken, it is imperative to analyze the potential of reducing GHGs and the associated cost through ecosystem conservation activities.

Tanzania has a very high deforestation rate, which has been estimated at about 400×10^3 ha yr^{-1} for pure deforestation (FAO, 1993), and as high as 750×10^3 ha yr^{-1} when forest degradation and harvesting are included and converted to a deforestation equivalence (Makundi and Okiting'ati 2000, op cit.). The high population increase estimated at 2.8% per year in 1998–99 (Planning Commission 2000), plus the high land-dependence of the population, suggests the likelihood

TABLE I
Conserved areas for wildlife management

Management category	Number of Units	Area (10^6 ha)	% of Total land area	% of area under threat of deforestation	Area under pressure (10^6 ha)
National parks	11	3.8	4.1	33	1.25
Ngorongoro conservation area	1	0.8	0.9	15	0.12
Game reserves	18	9.7	10.4	13.5	1.31
Game controlled areas	56	9.0	9.6	13.5	1.22
Total	86	23.3	25.0	17*	3.90

Source: MLNRT 1989.
* Weighted average.

of worsening of the deforestation rate and increase in the associated GHG emissions. Conservation mitigation activities can significantly reduce emissions from the forestry sector.

Conservation and protection can be directed towards currently unprotected areas and/or strengthening the protection of conserved areas which are under pressure from forces of deforestation and degradation. About 25% of the country's total land area is protected for wildlife management and conservation of ecosystems for biological diversity. A further 13×10^6 ha of the land is classified as forest reserves for production and conservation. Of the 3.8×10^6 ha under national parks, 2.0×10^6 ha are classified as reserved forests and woodlands. Table I gives a breakdown for wildlife management areas, as well as the proportion of the protected areas that are under pressure for deforestation activities.

The TFAP Report (1989, op cit.), suggests that about 13.5% of game reserve area is threatened with encroachment by pit sawyers, illegal logging, grazing, farming and peasant settlements. Also, 15% of the Ngorongoro Conservation Area is considered to be under pressure, that is, 5% from grazing and trampling and 10% from encroachment for farming on the slopes of Empakaai and fuel wood gathering from the neighboring areas like Karatu and Katete on the eastern border (Leader-Williams et al. 1996; Moehlman et al. 1996). All in all, the increasing population pressure and declining soil productivity around the conservation areas are likely going to exacerbate the encroachment problem. As such, measures to secure the currently conserved areas will reduce the C emissions from potential degradation/deforestation, as well as increase sequestration as the biomass density rises over time.

In this study we analyze the ecosystem conservation programs proposed in TFAP intended to expand the areas under protection.

TABLE II
Parameters and assumptions for Baseline scenario

Parameters	Areas to be converted to mitigation options		
	Short rotation community forestry	Long rotation softwood plantations	Long rotation hardwood plantations
Soil C (Mg C ha^{-1})	45	53	98
Vegetation biomass (m^3 ha^{-1})	32.5	15	39
Product prices*			
Firewood ($ m^{-3})	0.3	0.3	0.3
Honey and wax ($ ha^{-1} yr^{-1})	3.9	3.9	3.9
Other e.g. herbs, fruits ($ ha^{-1} yr^{-1})	2.0	2.0	2.0
Aboveground/Stemwood biomass ratio	1.57	1.57	1.34
Total/Aboveground biomass ratio	1.25	1.25	1.14
Wood density	0.89	0.89	0.58
Vegetation biomass (Mg DB ha^{-1})**	57	26	34
C density	0.53	0.53	0.52

Source: Malimbwi et al. 1998; Makundi and Okiting'ati 2000, op cit.
* Prices in constant 1986 dollars to allow the use of the same price for future products.
** DB = Dry Biomass.

3. Analytical Methods and Data

The Comprehensive Mitigation Assessment Process (COMAP) model was used to analyze the mitigation potential and costs of the options described above. This framework requires one to specify a baseline scenario and mitigation scenario, for which we estimated the C stock and costs of both scenarios. The difference between the two scenarios provides the incremental amount of C and costs due to the mitigation activity. For complete description of the model, see Sathaye et al. (1995). The assumptions and parameters used for estimating changes in stock under baseline and mitigation scenarios are presented in Tables II and III.

3.1. Baseline Scenarios

Most of the area to be used for the community afforestation is assumed to be from degraded miombo woodlands and intermediate transitional woodlands, whereas the ecosystem for the softwood plantation is mostly grasslands and bushy rangelands on the Mufindi plateau. The hardwood plantations will be established on the higher altitude lands with adequate precipitation in the northeast, west and southern Tanzania, which are of higher productivity than the woodlands.

TABLE III

Parameters and assumptions for mitigation scenario (equilibrium values)

Parameters	Short rotation community forestry	Long rotation softwood plantations	Long rotation hardwood plantations
Available area (ha)	1.7×10^6	25×10^3	90×10^3
Species	*Eucalyptus (maidenii, saligna, microcorys, globulus), Leucena leucocephala, & Melia spp.,*	*Pinus (patula, elliottii, carribaea), Cupressus lusitanica*	*Grevillea robusta, Tectona grandis* (teak), *Acacia seyal, Acacia mearnsii* (black wattle)
Average mean annual increment (m^3 ha^{-1} yr^{-1})1	36	30	10
Merchantible volume/Stemwood[2]	1.1	1.1	1.1
Stemwood/Aboveground biomass[3]	1.2	1.2	1.3
Total vegetation/ Aboveground[4]	1.3	1.3	1.3
Wood density[5]	0.65	0.45	0.655
C density[6]	0.48	0.48	0.52
Soil C (Mg C ha^{-1} yr^{-1})	1.0	1.0	0.5
Rotation age (yr)	8	25	60
Product Prices[7]			
Sawlogs (\$ m^{-3})	4.4	5.1	13.3
Chiplogs (\$ m^{-3})	2.2	4.3	8.9
Firewood (\$ m^{-3} solid)	0.3	0.3	0.3
Honey & wax (\$ kg^{-1})	3.9	–	–
Poles (\$ m^{-1})[8]	2.0	–	2.0
Vegetation biomass (Mg ha^{-1} yr^{-1})	40	23	12
Average product lifetime (years)[9]	17	17	21
Decomposition (yrs)	8	8	10
Discount rate	10%	10%	10%
Present Value of initial cost (\$ ha^{-1})	217	204	378
Recurrent cost (\$ ha^{-1} yr^{-1})	47	24	24
Net Present Value of benefits (\$ ha^{-1})	321	–1372	–378

[1]Ahlback, 1988. For site class I and II.
[2]Stemwood measured excludes tops and buttress.
[3]Aboveground includes branches, associate vegetation, detritus, etc.
[4]Total vegetation includes belowground biomass.
[5]Average for 3 common species (*P. patula, elliottii* and *caribaea*).
[6]Average for pines and cypress (see Malimbwi et al. 1998).
[7]The prices (and costs) were converted to US \$ at the time of TFAP proposal, and we assume that the relative prices (products versus inputs) have remained stable in 1989 \$ prices.
[8]Weighted average for 2.0 m, 2.5 m and 3.0 meter poles (Monela 2000).
[9]Weighted average over product range.

TABLE IV

C sequestration potential in major pools per hectare

Pool (Mg C ha^{-1})	Short forestry rotation community	Long rotation softwood plantations	Long rotation hardwood plantations
Vegetation C	77	139	190
Soil accumulation	8	25	30
Decomposing matter	28	13	14
Forest products	34	57	36
Total mitigation pool	147	233	270
Mitigation + baseline soil C	192	286	369
Baseline pool	75	61	116
Net mitigation potential	117	225	253

3.2. Mitigation Scenarios

Due to the uneven distribution of C accumulation in various pools over time, and because of the temporal differences in the stream of costs and benefits in forestry mitigation projects, the approach used in this framework distributes these three magnitudes evenly for the duration of the planning horizon. This process referred to as annualization enables us to estimate an equivalence of net C sequestration or emission reduction (Mg C ha^{-1} yr^{-1}) and net costs ($ ha^{-1} yr^{-1}) under given assumptions on management. For example, afforestation and reforestation projects are assumed to be managed in perpetuity, and conservation projects are supposed to persist beyond the planning horizon.

In this study, the analysis is done for perpetuity but the results are summed up for the first 40 years, with the summaries given for years 2000, 2008, 2010 and 2012. We also report the summaries for 2030 and 2039 and in the case of hardwood plantation for 2059 so as to have points far enough in the future for the non-C benefits to be accounted for. The parameters used for estimating the C sequestration and cost potential are obtained from analysis for the entire rotation of each option.

4. C Sequestration Potential and Costs

4.1. Sequestered C Pools

The analysis produced summary results for each of the three afforestation options, as well as cumulative estimate of periodic and potential equilibrium C sequestration and the associated cost over the planning horizon. Table IV shows the estimate of C sequestered in the four different pools for each option.

Though the community forestry option has less net C per hectare, the equilibrium is reached much earlier due to its short rotation cycle. Since most of the species for this option used 3 or 4 coppice cycles, it means that the C sequestered in root biomass has a rotation equivalent to the replanting cycle. This also increases the equilibrium total C sequestered. The hardwood option has a much higher equilibrium sequestration though it is reached much later than the other two. If there are no considerations with regard to the timing of the sequestration, then every thing else being equal, the longer rotation options will be much more attractive since they hold a higher sequestration pool per hectare at equilibrium. However, since project-based activities will have accreditation for real and certified emission reduction, the shorter rotation options will be more attractive for both sequestration and economic reasons.

4.2. Sequestration Potential

The short rotation option has a much higher potential due to the total area to be used for community forestry. Though the program takes off in a gradual pace with 12×10^3 ha^{-1} yr^{-1}, by 2012 it will have cumulative sequestration equivalence of about 50×10^6 Mg C rising to about 197×10^6 Mg C by 2024 when it reaches the maximum goal of producing 50% of the wood demand, about half of which will be for fuel wood and the remainder for construction, poles and chips for tertiary forest products.

The option is also profitable given the assumption on prices and costs even at a 10% discount rate. This is also made possible by the short rotations assumed for the option. The program is estimated to generate a present net worth of \$ 79.5×10^6 of non-C benefits between 2000 and 2030. The total present value of initial costs is \$ 85×10^6, and this may be a constraint for Tanzania even though the net benefits far exceed the investment. This could be one of the justifications for considering the option under the project-based activities so as to benefit from a foreign investor who would acquire rights to all or some of the C benefits of the project.

This option also underestimates the total C benefits because the alternative source of the biomass would have been natural forests, which are being degraded, and their recovery may not reach the pre-harvesting C equilibrium. In fact, the high deforestation rate may suggest that the option would have substantial emission reduction component. To be able to claim the emission reduction benefits, one would need to study the biomass utilization profile of the target communities, including rates of fuel switching and efficiency improvements in conversion and in use. A pilot study going hand in hand with the project could provide some of the answers to this question.

Table V presents a summary of the results for the three sequestration options studied. Both the softwood and hardwood plantations have much less C sequestration potential due to their smaller size. The softwood plantation will sequester about 5.6×10^6 Mg C while the hardwood option will reach about 22.8×10^6 Mg

TABLE V
C sequestration potential and cost

	2000	2008	2010	2012	2030	2039	2000–2030*	2059
Short rotation community plantations								
Incremental net benefit (10^3 \$)	279	5,048	7,095	9,886	39,290	39,290	79,496	–
Annualized benefit from converted land (10^3 \$)	963	17,412	24,473	34,101	135,523	135,523	274,205	–
Present value of initial costs (10^3 \$)	2,610	9,569	9,569	16,529	0	0	84,964	–
Annualized cost of mitigation (10^3 \$)	568	1,027	1,444	2,012	7,997	7,997	161,802	–
Cumulative incremental C pool (10^3 Mg C)	1,403	2,536	3,565	4,967	197,402	197,402	197,402	–
Cumulative afforested land area (10^3 ha)	12	217	305	425	1,689	1,689	1,689	–
Long rotation softwood plantations								
Incremental net benefit (10^3 \$)	–28	–255	–311	–368	–736	–736	–2,458	–
Annualized benefit from converted land (10^3 \$)	18	167	204	241	481	481	1,606	–
Present value of initial costs (10^3 \$)	185	185	185	185	0	0	1,681	–
Annualized cost of mitigation (10^3 \$)	51	456	557	658	1,266	1,266	4,396	–
Cumulative incremental C pool (10^3 Mg C)	225	2,024	2,474	2,924	5,622	5,623	5,622	–
Cumulative afforested land area (10^3 ha)	1	9	11	13	25	25	25	–
Long rotation hardwood plantations								
Incremental net benefit (10^3 \$)	–67	–606	–741	–876	–2,089	–2,695	–4,043	–5,937
Annualized benefit from converted land (10^3 \$)	0.08	0.70	0.86	1.02	2.43	3.13	4.70	6.90
Present value of initial costs (10^3 \$)	202	202	202	202	202	202	202	1,915
Annualized cost of mitigation (10^3 \$)	57	513	626	740	1,766	2,278	3,417	5,019
Cumulative incremental C pool (10^3 Mg C)	379	3,412	4,171	4,930	11,755	15,168	11,755	22,752
Cumulative afforested land area (10^3 ha)	1.5	13.5	16.5	19.5	46.5	60.0	90.0	46.5

* For the monetary entries, the column shows cumulative present value at 10% discount rate.

C over a much longer period. Both these projects are not cost-effective at 10% discount rate given the assumptions on product prices and input costs. The softwood plantation will lose about \$ 2.5×10^6 of present worth while sequestering about 5.6×10^6 Mg C through 2030, and the hardwood plantations would lose about \$ 4.0×10^6 while sequestering about 11.8×10^6 Mg C through 2030 or 22.8×10^6 Mg C by the end of the 60 year rotation. The three sequestration options will sequester a total of 215×10^6 Mg C between 2000 and 2030, approximately 7.5×10^6 Mg C at a positive NPV of \$ 2.46×10^6 yr^{-1}.

Examining the incremental benefits or net present value tends to blur the factors which make these activities conducive for project-based mitigation activities investment. Even though the short rotation option is cost effective, there is an asymmetry between the stream of costs and that of benefits, with a large proportion of costs being invested during establishment and early silvicultural operations, while most of the benefits are realized towards or at the end of rotation period. The rows in Table V showing annualized cost and benefits of the mitigation activities allows for the comparison of these parameters at common time frames, but conceals the barriers arising from the skew. Many investors in developing countries, including governments, have difficulty raising the finances necessary for the initial investment. This is one of the reasons why these projects have not been implemented though they were proposed some years back. This fact may address the additionality condition for mitigation projects, and their attractiveness to investors from Annex 1 countries becomes more dependent on the potential to sequester C and the associated cost per tonne of C.

The long rotation project shows a very small annualized benefit because they are discounted from so far in the future. Inclusion of intermediate products and use of a lower discount rate will enhance the cost effectiveness of such long-term projects.

4.3. Cost Effectiveness

Table VI gives a summary of the cost effectiveness of the mitigation options discussed above. All the options have less than \$ 1.0 for present value of cost, and as mentioned before, the short rotation option has a positive NPV at 10% discount rate. Even at as low discount rates as 2% the other two options were still not cost effective, though the net NPV Mg^{-1} C is still below \$ –1.0, implying that the value of the C credit at-cost is quite competitive compared to energy or industry options.

The short rotation option has a much higher initial cost and endowment cost per Mg C sequestered, while the long rotation hardwood plantation has a much lower cost per Mg C compared to the other two options. On a per Mg C basis, if an investor is indifferent about the non-C benefits, the long rotation hardwood plantation would be the most attractive, followed by the softwood plantation. However, the cost effectiveness of the short rotation community plantation will likely be more attractive to the host country and may be more sustainable than the other

TABLE VI
Cost effectiveness of mitigation options

	Short rotation community forestry	Long rotation softwood plantation	Long rotation hardwood plantation
Initial cost ($ Mg^{-1} C)	0.43	0.30	0.09
Establishment cost ($ ha^{-1})	50	67	22
Present value of cost ($ Mg^{-1} C)	0.94	0.78	0.27
Present value of cost ($ ha^{-1})	110	176	68
Net present value of benefits ($ Mg^{-1} C)	0.46	–0.60	–0.32
NPV of benefits ($ ha^{-1})	53	–136	–81
PV of investment to 2030 (10^6 $)*	161.8	4.4	5.0
Total sequestration to 2030 (10^6 Mg C)	197.4	5.62	11.76
Area (10^3 ha)	1,689	25	90

* Present value of all cost for the whole program.

two options. It also offers the only opportunity for sequestering a large amount of C through project-based activities, while meeting critical national demand for biomass.

4.4. Conservation of Ecosystem and Genetic Resources

As described above, the TFAP proposed an extensive program to enhance the conservation effort on the existing protected areas, as well as adding new areas to the national conservation network. The proposed new areas would add 186 × 10^3 ha in 21 conservation units to the country's protected areas, 17 of the units consisting of rain forests and sub-tropical forests, and the remainder are miombo ecosystems (MLNRT 1989). In this study we briefly discuss and compare the results of the sequestration opportunities analyzed above to the emission reduction potential and costs of the TFAP conservation.

As reported in Makundi and Okiting'ati (1995, op cit.) the cost of protection varies widely depending on the specific vulnerability and the resource characteristics of the protected unit. On the basis of annual expenditures of a variety of protection projects in Tanzania, it was estimated that the average cost of protection was $ 2.90 ha^{-1} per year. This number could not easily be translated to cost per Mg C yr^{-1} because only a small proportion of the C in the entire protected area was threatened, and that the bulk of the protection cost is incurred at the beginning of the project.

Analysis of the new proposed protection areas showed that it would cost about $ 35 × 10^6 to protect the 186.38 × 10^3 ha, with C stock amounting to 30.3 × 10^6 Mg C (Table VII). If the units were wholly vulnerable, implying that over time

TABLE VII
Conservation of ecosystem and genetic resources

Forest type	Area (10^3 ha)	Conserved C (10^6 Mg C)	Unit cost (\$ Mg^{-1} C)	Total cost (10^6 \$)
Rain and subtropical forests	168.08	29.204	0.81	23.77
Miombo forests	18.30	1.07	10.41	11.14
Total conserved area	186.38	30.274	1.27	34.91

Adapted from Makundi and Okiting'ati, 1995 op cit.

they would lose all the biomass, then the cost of protection would amount to \$ 1.27 Mg^{-1} C over the project period.

In order to evaluate the measures to contain the process of losing conserved areas we need an understanding of the specific land use conflict surrounding each affected area as well as the alternative opportunities available to the proximal population. The direct measures to stem the encroachment involves clear demarcation of borders, monitoring of land use activities, and enforcement of the applicable rules and by-laws. The cost of conservation and protection alluded to above is mostly for covering these direct measures.

By extending the findings shown in Table I which give an estimate of 17% of the 86 units which are currently protected in Tanzania as being under pressure for land use change, we can assume that the new areas have similar levels of vulnerability to deforestation and consequent reduction of the C stock. This would imply that the \$ 35×10^6 is for protecting the vulnerable frontier, and that in order to protect the whole area for the longer term, one would need about \$ 206×10^6, that is, 35/0.17, which is equivalent to \$ 7.5 Mg^{-1} C to successfully protect the 30×10^6 Mg C. In the absence of monetary benefits from the conservation option, this cost of protection is equivalent to the present value of costs for the sequestration projects analyzed above, where the short rotation community forestry had a cost \$ 0.94 Mg^{-1} C and the softwood plantation costing \$ 0.67 Mg^{-1} C, with the long rotation hardwood plantation being the cheapest with \$ 0.27 Mg^{-1} C. Using this approach, the conservation and protection options considered here were found to be much more expensive for GHG mitigation purposes than the afforestation options. An advantage of the conservation project is that the amount of annual avoided emissions is quite large due to the amount of C stock being protected.

It is noteworthy that the actual cost of conservation will depend on the interplay of many non-monetary factors, such as resource management policies e.g. shared ownership and management of the protected area, rural development policies, education, etc. In the long run, policies have to be instituted to re-direct the non-sustainable use of the land as well as provide some developmental alternatives to the people who are responsible for the encroachment. However, in the absence of a viable alternative means for the community to earn a living, the cost of protection quickly becomes very exorbitant, and can only be justified by the core environmental reasons behind the conservation project such as biodiversity and cultural or world heritage ecosystem.

5. Conclusion

The forestry sector in Tanzania occupies close to half the country's land area, estimated at about 42×10^6 hectares. The level of socio-economic development compels the population to inordinately depend on the use of forests for provision agricultural and grazing land, as well as charcoal and firewood woodfuel and other timber products. For example, it is estimated that more than 90% of the country's demand for primary energy is obtained from biomass, mostly procured unsustainably from the natural forests. These activities lead to significant emissions of GHGs as well as degradation of the forest ecosystems. Thus the Tanzanian forest sector provides ample opportunities for GHG mitigation, and CDM is one avenue through which this environmental service can be obtained.

This study examined the potential to sequester C through expansion of forest plantations aimed at reducing the dependence on natural forests for woodfuel production, as well as increase the country's output of industrial wood from plantations. Three options were analyzed, involving planting about 1.7×10^6 hectares with short rotation and long rotation trees, aimed at meeting about 50% of the woodfuel demand and a significant portion of the demand for industrial wood. The short rotation community forestry option was found to have a potential to sequester a cumulative equilibrium total of 197.4×10^6 Mg C by 2024, while earning a net benefit of \$ 79.5×10^6 thus yielding a NPV of \$ 0.46 Mg^{-1} C. The long rotation options for softwood and hardwood plantations are estimated to sequester 5.6 and 11.8×10^6 Mg C at a negative NPV of \$ 0.60 Mg^{-1} C and \$ 0.32 Mg^{-1} C respectively. However, the amounts of C that could be sequestered will depend on constraints and factors such as environmental and resource policies and institutions, markets for forest products, barriers to implementation, and structure and markets for GHGs. The three options considered in this study were found to be cost competitive options for sequestering about 7.5×10^6 Mg C per year while providing desired forest products and easing the pressure on natural forests in Tanzania. The cost of C sequestration was compared to that of emission reduction in conservation options and on average the three options were more attractive in terms of endowment cost. Under assumptions of ecosystem vulnerability comparable to that of the existing conservation areas, the average cost for conservation was found to be as high as \$ 7.50 Mg^{-1} C of avoided emissions.

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